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ABSTRACT

Since Precambrian time, zones of weakness have been repeatedly but infrequently reactivated in the Mississippi Embayment area. All of the major folds and many of the minor anticlines caused by this activity are associated with faults in the basement rocks. The latest occurrence of major tectonic activity (perhaps Early Cretaceous), however, not only affected the old fault zones but also created a vast new feature, the Pascola arch, which has no Paleozoic antecedent. Severe erosion and subsequent Tertiary subsidence associated with the Pascola arch indicate that this structure alone is the locus of present-day major earthquake activity. Until the time in the geologic future when old established zones of weakness are reactivated regionally, only the relatively young Pascola arch will continue to be the focal point of high intensity earthquake activity in the Embayment area.

INTRODUCTION

On the basis of an examination of the Paleozoic sedimentary record in the Embayment area, the distribution and history of tectonic structures within a 200-mile radius of New Madrid, Missouri, are interpreted here in an effort to clarify their role in earthquake distribution and frequency. Begun as an investigation of the nature of recent seismic activity in the region, the New Madrid seismotectonic study has incorporated the stratigraphic and structural geologic parameters relating to earthquake activity.

Well cuttings from selected deep tests drilled in the area were studied to determine their lithology as well as the presence of microfossils, igneous intrusives, and metabentonites. To increase understanding of the tectonic events leading to interruptions in the sedimentary record, the magnitude and extent of unconformities were appraised by detailed stratigraphic correlation based partly on geophysical logs. Samples of igneous intrusives and crystalline basement rocks were collected for age dating by radiometric methods, and age dates were obtained from private and published reports.

Much useful information was obtained from the files of state geological surveys and universities, and I gratefully acknowledge the help and criticism from the following individuals: Kenneth Anderson, Missouri Division of Geological Survey and Water Resources; Jerry Carpenter and Andrew Hreha, Indiana Geological Survey; William Caplan, Arkansas Geological Commission; Alvin Bicker, Jr., Mississippi Bureau of Geology; Robert Hershey and Ned Luther, Tennessee Division of Geology; Jack Kidd, Geological Survey of Alabama, and all the members of the New Madrid Study Group. I assume sole responsibility for the interpretation of the data and the conclusions presented in this report.

TECTONIC HISTORY OF SELECTED GEOLOGIC FEATURES

Ozark Uplift

The oldest tectonic element recognized in the area is the Precambrian Ozark uplift (Fig. 1). It is believed that the igneous rocks exposed in the St. Francois Mountains of the southeastern Missouri portion of the uplift represent a major petrogenic epoch of relatively short duration in Late Precambrian time (Tolman and Robertson, 1969). Precambrian marine invasion of the Ozark uplift area is documented by the presence of stromatolitic limestones with a minimum age of 1,400 m.y. (Stinchcomb, 1976). The next sediments were deposited in Late Cambrian time.

Within the study area, no other Precambrian rocks have been identified in the vicinity of the St. Francois Mountains. The contact between the sedimentary rocks and crystalline rocks is sharp, with no appreciable weathering profile noted in the outcrops or subsurface. Debris transport must have kept the region clear of weathered products.

Although subject to infrequent marine incursion, the Precambrian terrain of the Ozark uplift was the dominant topographic feature throughout the Paleozoic.

The topographically lower region surrounding the uplift contained numerous hills and ridges, some of which were more than 500 feet high. Some of the ridges of crystalline rock were probably accentuated by bordering faults, and these faults probably affected later faulting of overlying sediments.

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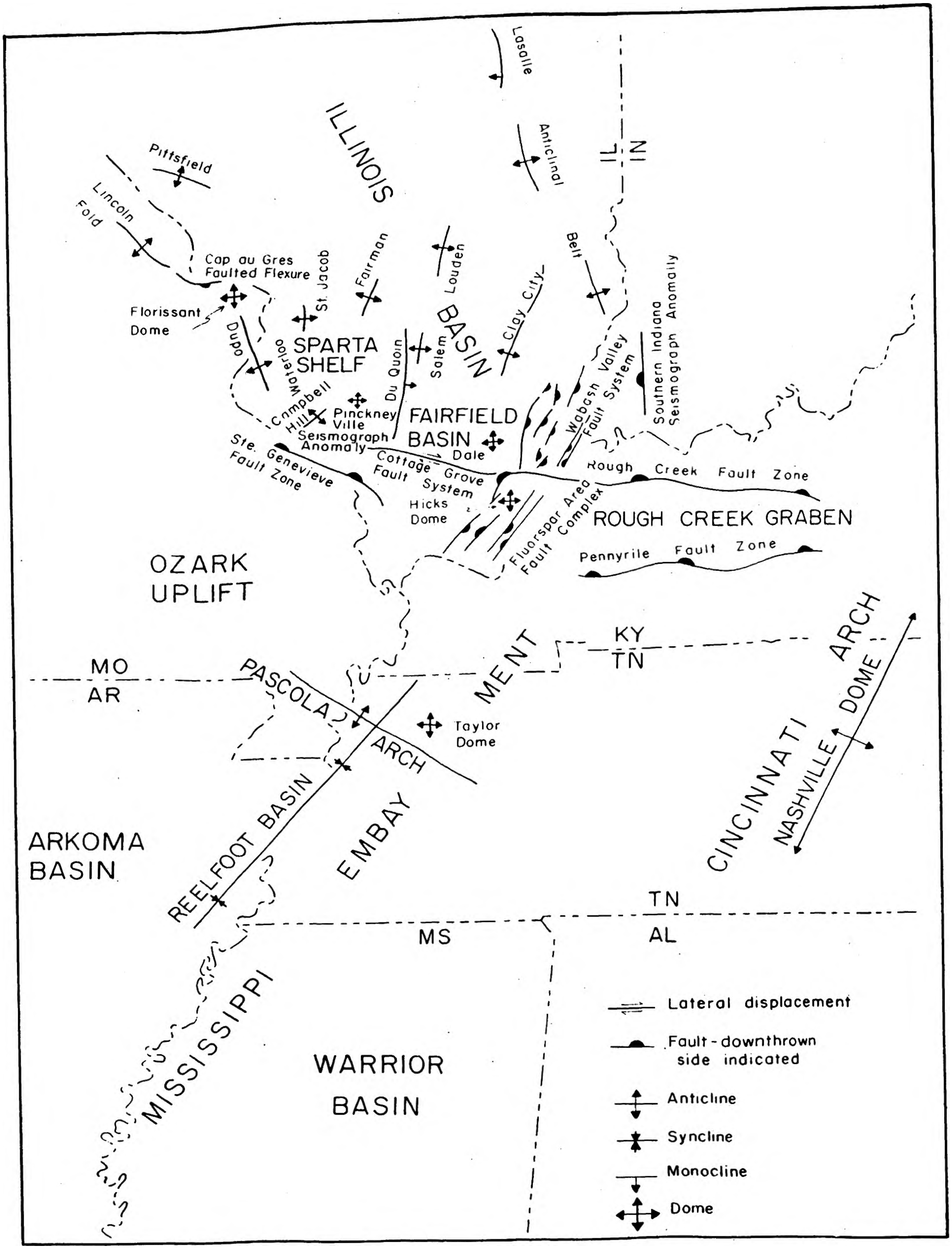

Fig. 1. Tectonic setting of the southern part of the Illinois basin and Mississippi Embayment.

Mississippi Embayment Rift

A major tectonic event, which probably occurred at the end of Precambrian time, opened a rift that extended from northeastern Arkansas into southern Illinois. The rift flanked the eastern edge of the Ozark uplift and affected crustal rocks for about 100 miles eastward. The edges of the rift zone apparently were step-faulted parallel to the central graben, where total displacement to the center of the rift probably exceeded 5,000 feet. With one anomalous exception, no well has penetrated the basement rocks within the Mississippi Embayment rift, and the nature of the sediments in the bottom of the rift zone is unknown. However, marine waters probably entered the graben from the south or southwest, and Lower Cambrian sediments probably are present in the deep portions.

The one exception mentioned occurs in the Big Chief #1 Taylor well in Gibson County, Tennessee, which encountered the Precambrian basement at 6,900 feet. The radiometric date of the igneous cuttings from this well is about 680 m.y., which is an unusually low value (Robert Hershey, personal communication). The isopach of Pre-Knox strata (Fig. 2) shows the anomalously thin sedimentary interval above the basement in the well. The interval contains neither basal sands nor shale. Instead, dolomite of presumed Late Cambrian age rests directly on the crystalline basement. The name Taylor dome was given to this anomalously high basement feature.

Two possible explanations for the shallow basement depth and lack of clastic pre-Knox sediments in the #1 Taylor are related to rift zone genesis. The well might have penetrated an upthrown block, or horst, created by rift-associated faulting, however, the forces causing rifting were tensional and thus not likely to have produced an uplifted block of crystalline rock near the center of spreading. The other possible explanation is based on the presence of extrusive igneous plugs or cones, which might have stood well above the surrounding landscape and might have been preserved long enough to be buried under sedimentary cover. Such extrusions probably would have been contemporaneous with rifting, and the dating of these rocks at 680 m.y. would indicate that the rift was of latest Precambrian age.

Rough Creek Graben

During the rifting in the Mississippi Embayment area, the eastern block containing the Nashville dome began to rotate toward the southwest. This rotation created two zones of weakness that produced the Rough Creek graben, which extends eastward from the northern end of the Mississippi Embayment rift. The Rough Creek and Pennyrile fault zones, respectively, mark the northern and southern borders of this graben, which was downdropped several thousands of feet. The graben narrows in width from about 35 miles on the west to about 15 miles on the east. The bounding fault zones curve toward each other at the eastern end of the graben and may connect in the subsurface in vicinity of eastern Grayson and Edmonson Counties, Kentucky. The two fault zones were reactivated repeatedly during the Paleozoic Era, allowing the Rough Creek graben to deepen and acquire a thick accumulation of sediments. Whether or not the bordering faults of the Mississippi Embayment rift were similarly reactivated in the Paleozoic is unknown, because erosion has removed most of the post-Ordovician rocks in that area.

In the Texas Gas Exploration #1 Shain well in Grayson County, Kentucky, a thick Middle Cambrian marine shale section occurs beneath the Upper Cambrian Eau Claire Formation (Fig. 3, well #4). The bottom of this test, which stopped in the sedimentary section, encountered 2,360 feet of shale with thin arkosic streaks and a few thin beds of oolitic limestone. The shale contains linguloid brachiopods and a few trilobite fragments, which provide a means of dating the formation. An agnostid trilobite was identified by Christina L. Balk as the genus *Baltagnostus,* an index of upper Middle Cambrian age. Additional specimens examined by Michael E. Taylor of the U.S. Geological Survey were also recognized as being of questionable Middle Cambrian age.

In wells penetrating the crystalline basement north of the Cottage Grove and Rough Creek faults, the Mt. Simon Sandstone of Late Cambrian age is the oldest sedimentary unit found.

Lower and Middle Cambrian rocks lap onto the Nashville dome from the Appalachian basin, but they thin and disappear in north-central Tennessee, where lower Knox dolomite of Late Cambrian age rests directly on the basement. The Nashville dome segment of the Cincinnati arch may have begun to take form in Early Cambrian time, as it seems to have prevented Lower and Middle Cambrian sedimentation to the east of the Rough Creek graben (Fig. 4).

Reelfoot Basin

Although no Lower Cambrian rocks have yet been identified on the surface or in the subsurface, they are presumed to exist in the bottom of the Embayment rift and in the Rough Creek graben. One can only speculate as to the lithology and thickness of any Lower Cambrian rocks there, but the sedimentary units would most likely be arkosic

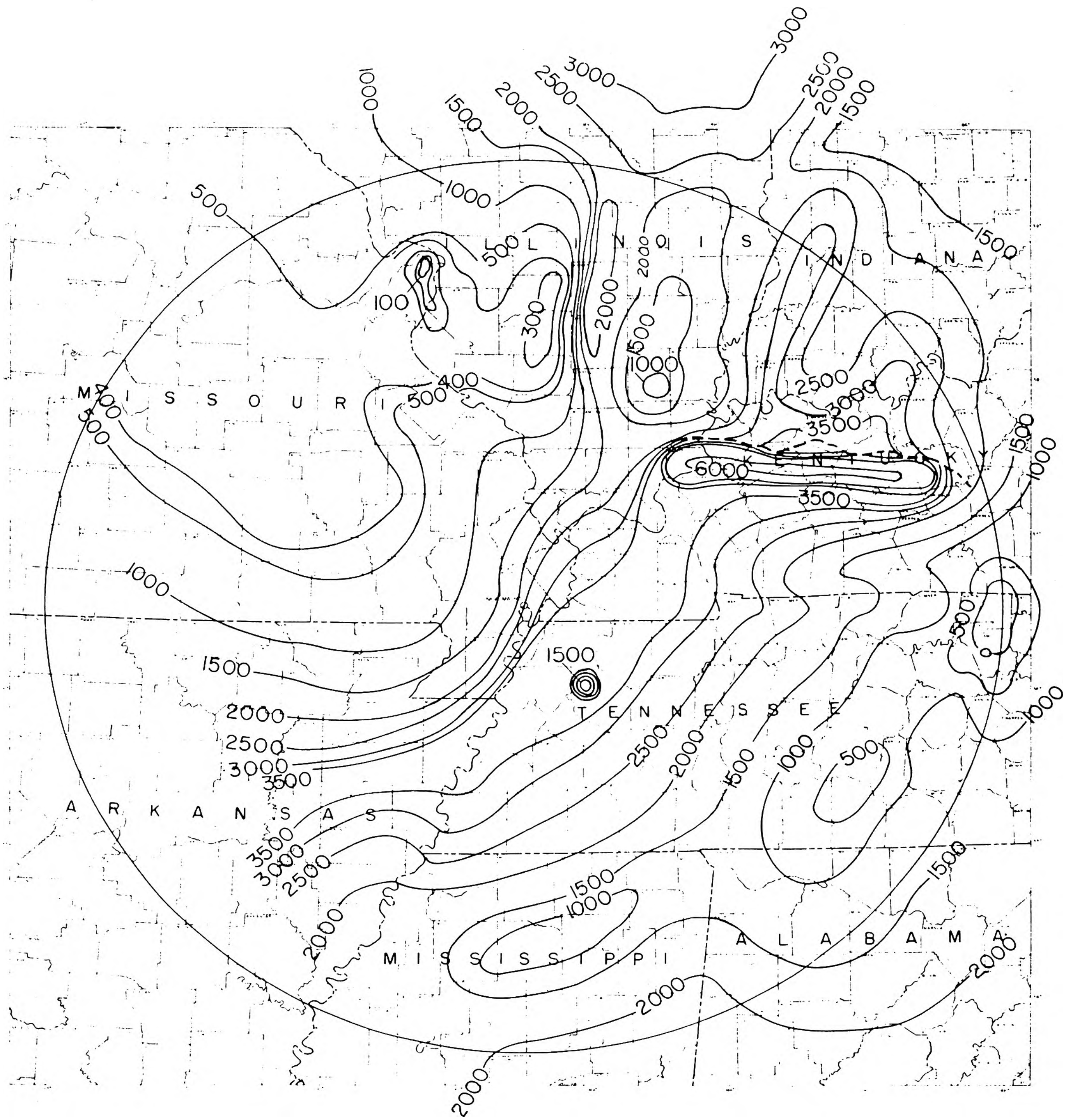

Fig. 2. Isopach map of pre-Knox strata in south-central United States.

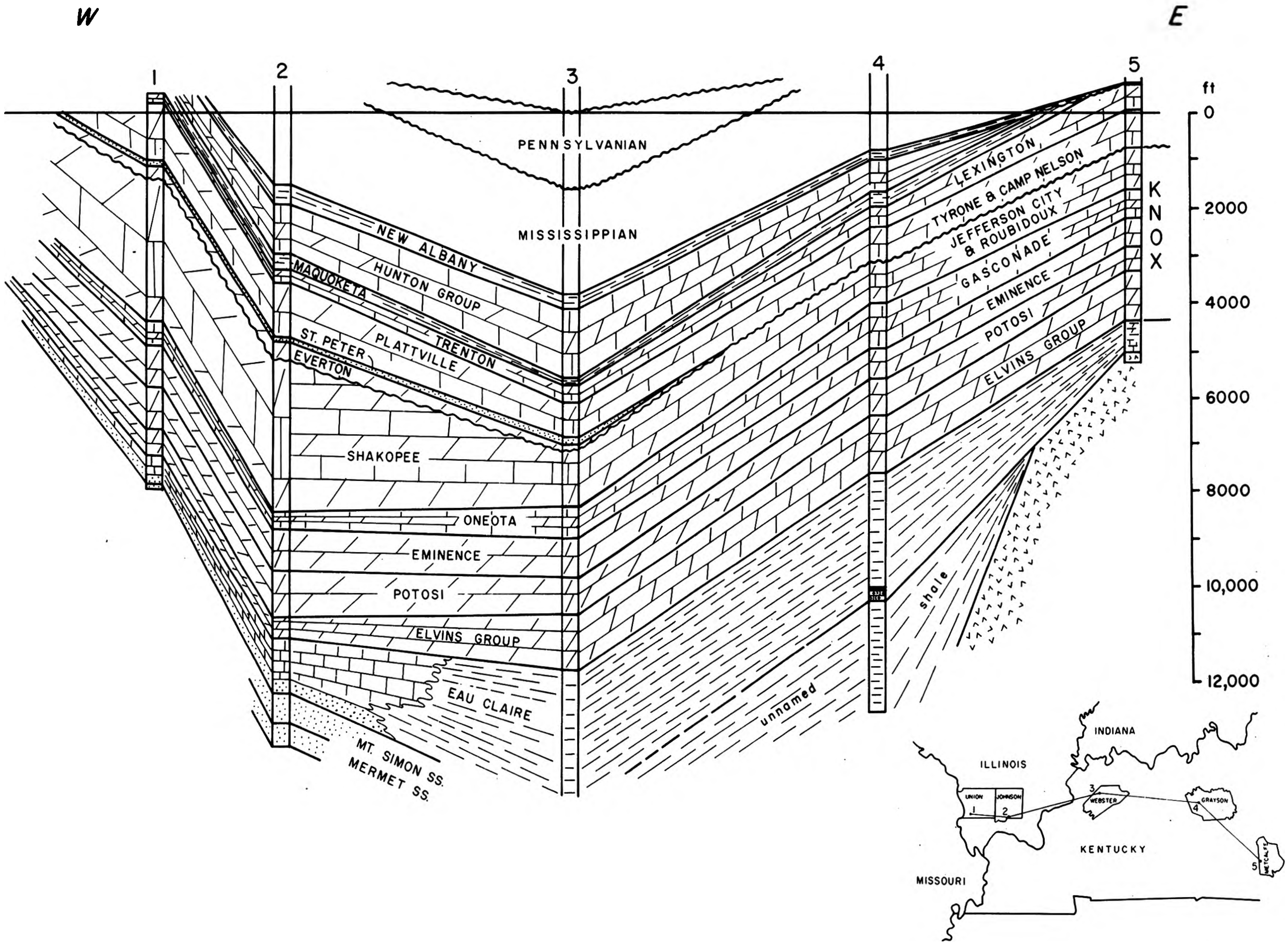

Fig. 3. East-west cross section south of the Rough Creek and Cottage Grove faults.

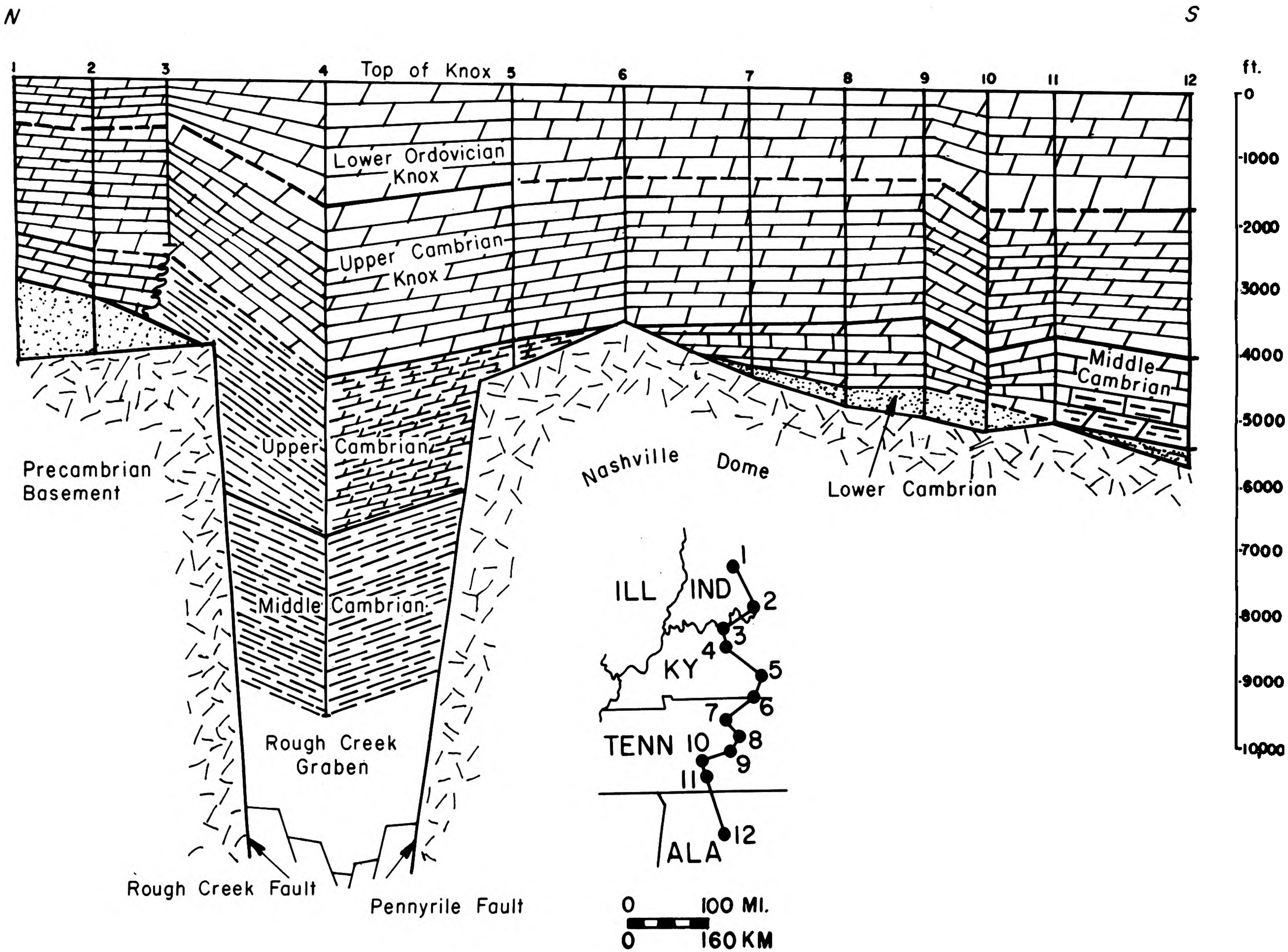

Fig. 4. North-south cross section parallel to but east of the Mississippi Embayment area.

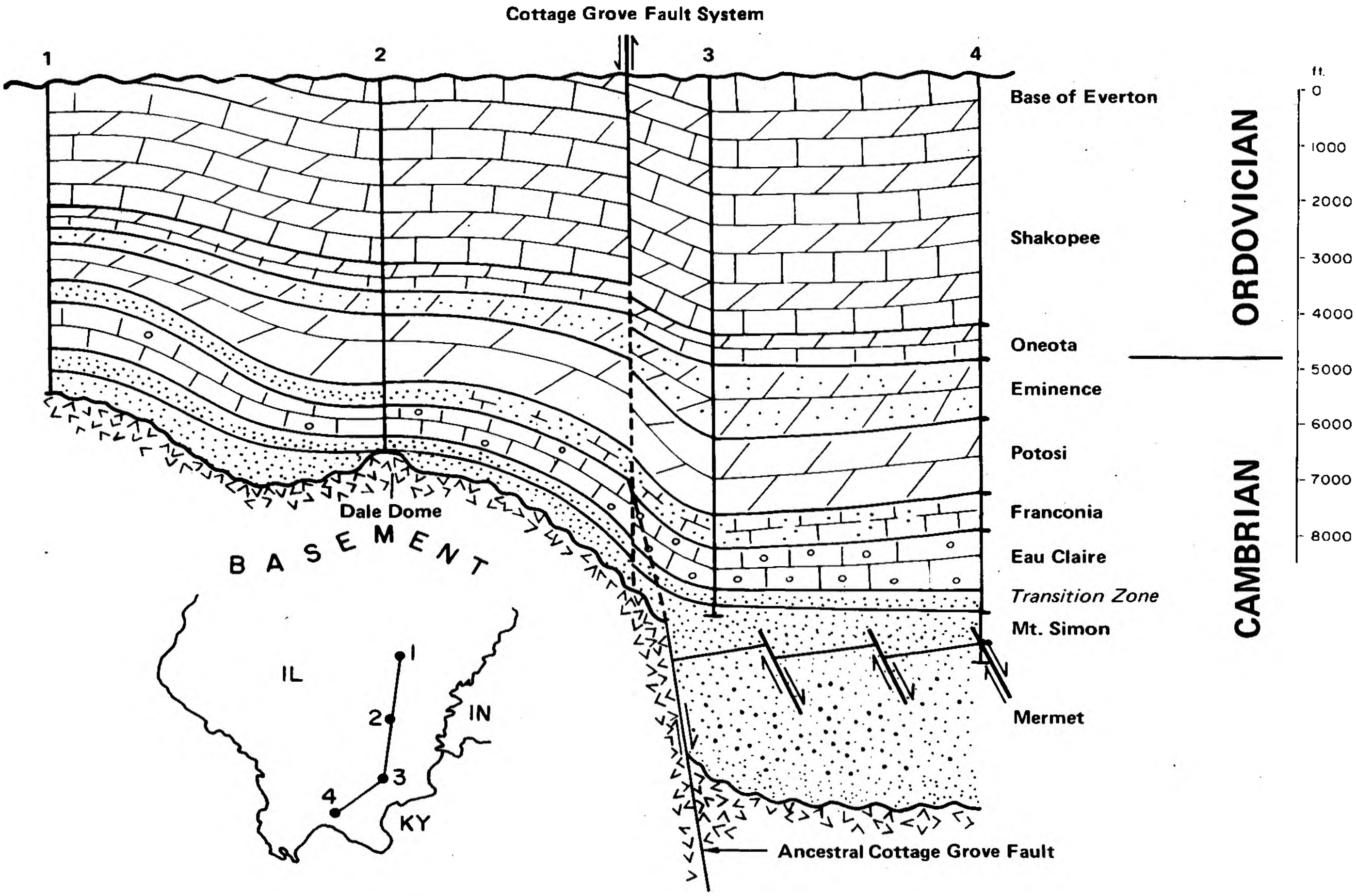

Fig. 5. North-south cross section of pre-Everton strata at the north end of the Mississippi Embayment.

sands, derived from the exposed crystalline terrain. These could be several thousands of feet thick in the deepest portions of the rift system.

The Reelfoot basin (Schwalb, 1969) occupies a portion of the trough of the Mississippi Embayment rift and contains an accumulation of Cambrian and Ordovician sediments estimated to have been at least 12,000 feet thick. Two wells within the basin, the Texas Pacific #1 Farley in Sec. 34, T. 13 S., R. 3 E., Johnson County, Illinois, (Fig. 5, well #4) and Benz #1 Merritt Estate in Sec. 3, T. 4 S., R. 1 E., Lake County Tennessee, (Fig. 6, well #5) penetrated rocks believed to be Middle Cambrian in age or older.

During middle to late Paleozoic time, depocenters shifted northward yet remained south of the Cottage Grove and Rough Creek faults. Later uplift exposed the rocks in the center of the Reelfoot basin, and a vast amount of sedimentary section was removed by erosion; therefore, the thickness of the total accumulation of sediments in the basin can only be estimated.

Arkoma Basin

The Arkoma basin trends westward from the Mississippi Embayment rift. Its eastern portion in northeastern Arkansas is younger than the Reelfoot basin. Lack of data from deep wells and the absence of basement tests in the central eastern portion of the Arkoma basin prevent the reconstruction of the early history of this region. Although they thin westward into the Arkoma basin, Knox strata are lithologically similar to those of the Reelfoot basin. Likewise, Middle and Upper Ordovician strata in the Arkoma basin are lithologically similar to but much thinner than those in the Illinois basin. Only parts of the Silurian, Devonian, and Mississippian Systems are present in the eastern portion of the Arkoma basin, and these parts are very thin in comparison to the parts of the same systems in southern Illinois. From their northern erosional limit, Pennsylvanian strata thicken southward and westward into the Arkoma basin. The sediments that formed

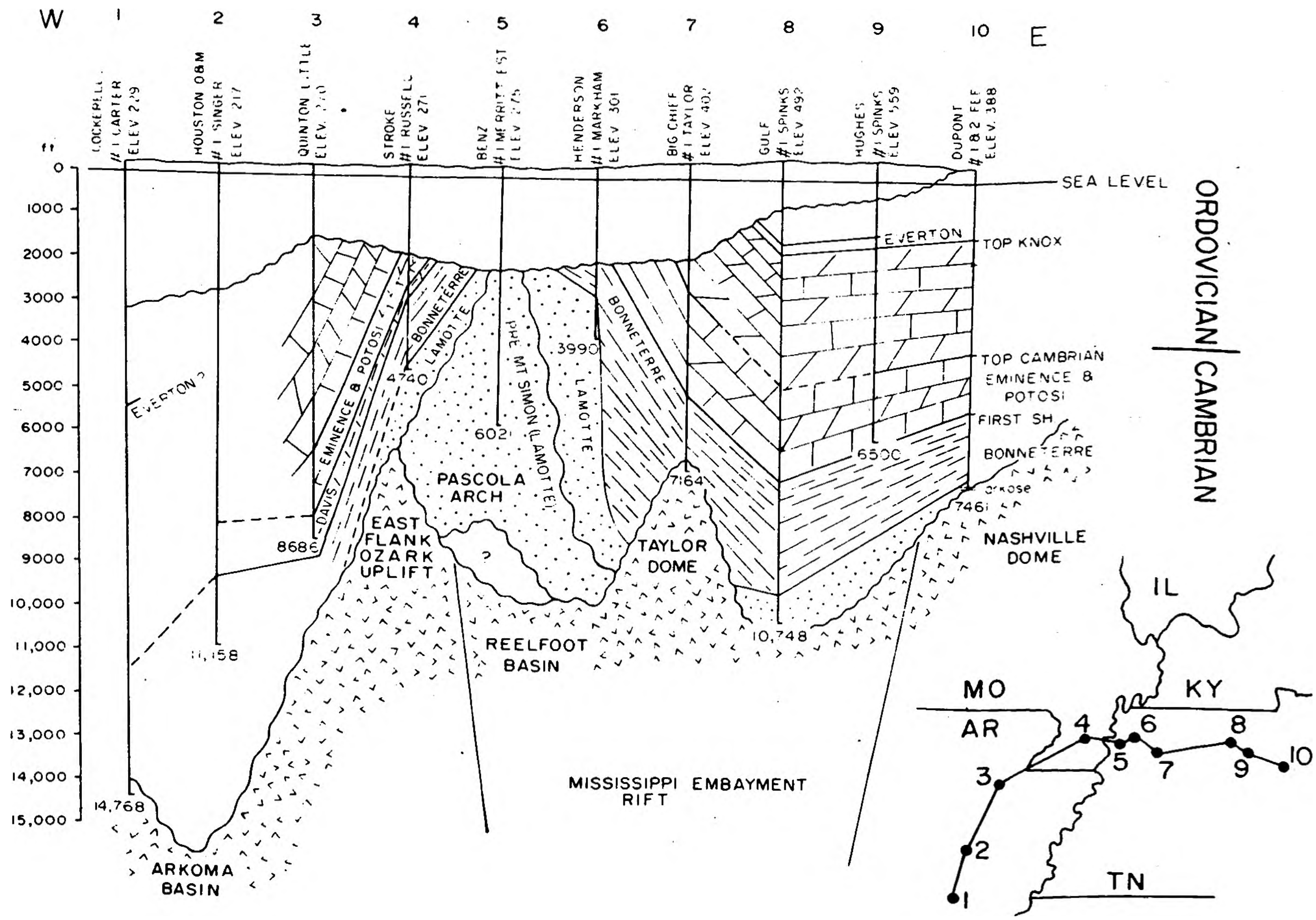

Fig. 6. East-west cross section of the Mississippi Embayment rift.

these strata are believed to have had the same easterly and northeasterly source as those of the Illinois basin. If, during Pennsylvanian time, the Illinois basin was connected to the Arkoma basin, so probably was the Reelfoot basin. The maximum thickness of Pennsylvanian strata in the Illinois basin is about 3,200 feet in Union County, Kentucky. The Pennsylvanian strata in Arkansas are over 10,000 feet thick.

Warrior Basin

The Warrior basin of Alabama and Mississippi appears to have a history similar to that of the Arkoma basin in that the rocks of the early Paleozoic are lithologically similar to but thinner than those in the Reelfoot basin. The Pennsylvanian section thickens dramatically from the Illinois basin southward to near the southern end of the Warrior basin where the Pennsylvanian section is more than 10,000 feet thick. Late Pennsylvanian or post-Pennsylvanian tectonism produced extensive faulting and folding as well as weak metamorphic alteration of the rocks in the southern Warrior basin and the southern Arkoma basin of Arkansas. The line of demarcation between the rocks exhibiting metamorphic alteration to the south and the unaltered rocks to the north is called the Ouachita Front in Arkansas. It trends from the west to the east where it is buried beneath the sub-Cretaceous unconformity and takes a more southerly trend toward Mississippi and Alabama.

Pascola Arch

The site of the buried Pascola arch extends from extreme northwestern Tennessee to southeastern Missouri (Grohskopf, 1955). Uplift of this arch closed the Illinois basin on the south and domed the sediments of the Reelfoot basin, exposing them to subaerial erosion. The uplift, which exposed pre-Lamotte sediments at its crest, affected an area of more than 15,000 square miles (Fig. 7). Erosional debris in the form of gravel and boulders was deposited in an arc that extends from the

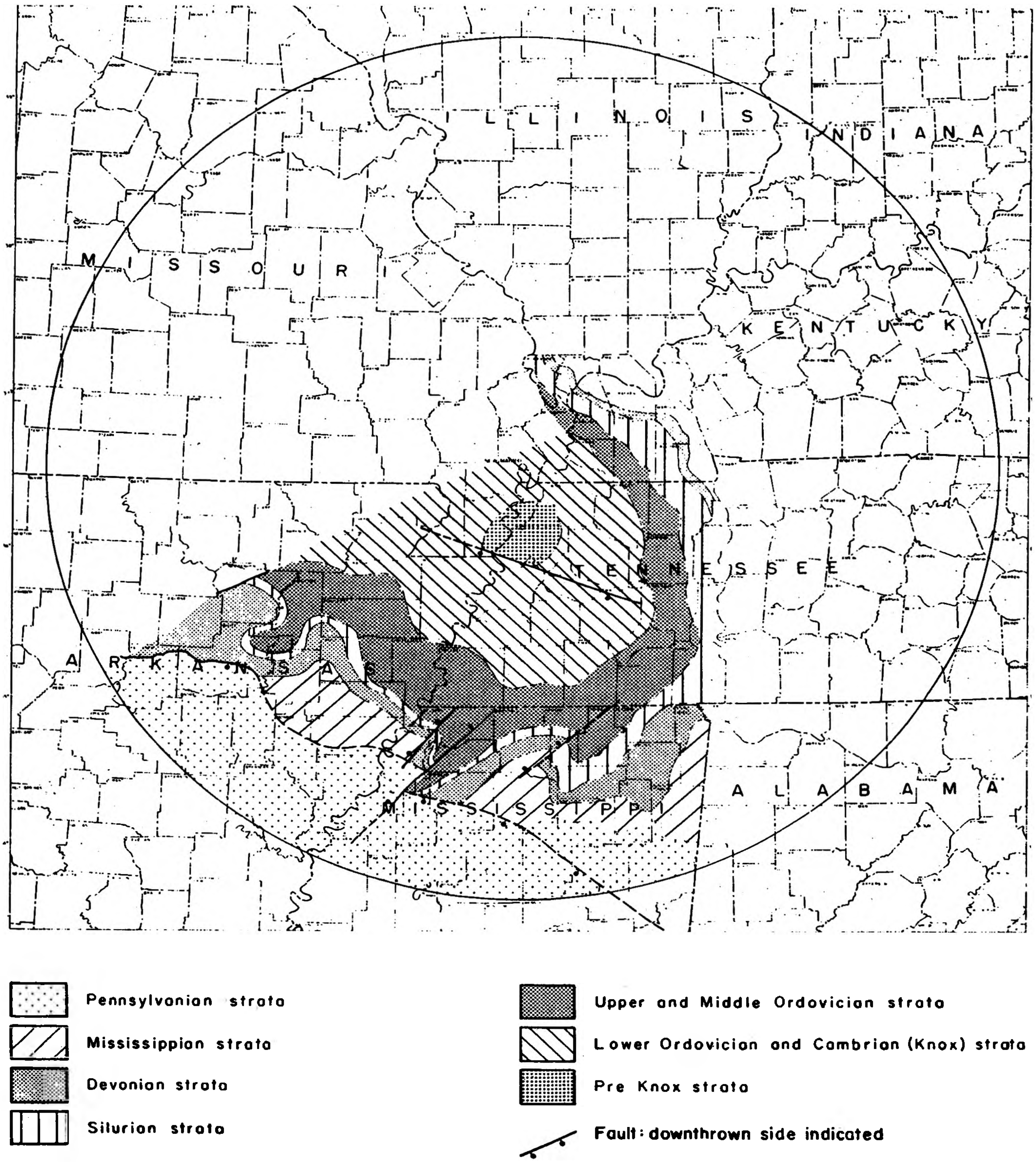

Fig. 7. Pascola arch in northwestern Tennessee and northeastern Arkansas.

northeast to the south around the arch. This debris was derived from the Upper Cretaceous Tuscaloosa Formation (Marcher and Stearns, 1962). Uplift of the arch was undoubtedly accompanied by faulting and perhaps by the emplacement of plutons (Hildenbrand and others, 1977). Uplift of the Pascola arch cannot be dated more precisely than as post-Pennsylvanian and pre-Upper Cretaceous. Erosion effectively planed the northern part of the Mississippi Embayment before downwarping allowed renewed sedimentation. Upper Cretaceous and Tertiary strata of both marine and nonmarine origin then filled the depression. These strata cover most of the Paleozoic rocks that were involved in the uplift of the arch and thoroughly mask the structure.

Post-Pennsylvanian Reactivation

Probably at the same time that the Pascola arch was uplifted, many of the earlier-formed faults and uplifts were reactivated throughout the region. The Rough Creek fault zone was displaced with some reverse movement, especially along its western portion. Here, as much as 3,000 feet of vertical movement is indicated on the south of the zone. At this location, Devonian beds have been elevated to a position where they are in contact with Pennsylvanian rocks. In a graben in Union County, Kentucky, rocks as young as those of Early Permian age are present. Activity along the fault zone was not as pronounced to the east, where the zone has the appearance of a tensionally stressed anticline. Here horsts expose Mississippian rocks, and graben blocks preserve Pennsylvanian rocks. The final displacement of the Rough Creek zone is down to the north, a reversal compared to earlier movement. In westernmost Kentucky, the south side of the zone dips very steeply into the Moorman syncline (Rough Creek graben) and may indicate an additional fault in the crystalline basement along the axis of the syncline with sufficient throw to accommodate the steep dip at the surface.

As much as 4,000 to 5,000 feet of sediment are believed to have been eroded from above the present surface of western Kentucky and southern Illinois. The recently exposed portion of the fault therefore was deeply buried when the last movement took place. Small compressional features currently exposed within the Rough Creek fault zone are thought to be the result of squeezing of internal blocks at pivot points as the north side and south side of the zone tilted away from each other.

Northeastward and eastward trending block faults in the fluorspar district of southern Illinois and western Kentucky as well as the Wabash Valley faults, which have a more northerly trend at the western end of the Rough Creek fault zone, are dated as post-Pennsylvanian. Renewed movement along the LaSalle anticlinal belt in Pennsylvanian time probably continued beyond that period (Clegg, 1965). The Du Quoin monocline, Salem and Louden anticlines, Cottage Grove fault system, and Ste. Genevieve fault, all experienced Pennsylvanian or post-Pennsylvanian tectonic activity.

A vast system of primarily northeast-southwest oriented erosional valleys marks the regional unconformity between Pennsylvanian and older strata in the Illinois basin. The valley courses do not seem to have been affected by preexisting structures except for the Du Quoin monocline.

Regionally, it would appear that there was rather gradual reactivation of many older faults and folds during Pennsylvanian time. A more violent and widespread adjustment of the basement rocks resulted in increased accentuation of these features in post-Pennsylvanian time. The evidence seems to suggest that the origin of the Pascola arch and the pronounced reactivation of all the basement-related features occurred during the Mesozoic Era, probably early in Cretaceous time. However, the lack of Triassic and Jurassic sedimentary rocks in the region does not preclude that major displacements may have occurred earlier in the Mesozoic.

Since this last period of major tectonic activity, there has been widespread erosion in the Illinois basin area, and to the south, downwarping of the Mississippi Embayment area has allowed the accumulation of sediments in the resulting southward-deepening trough. The most recent tectonic relationship between the Mississippi Embayment and the Illinois basin has been one of stability or uplift to the north and subsidence to the south. Current seismic activity seems to be most active in the area of subsidence.

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LIST OF WELLS

Figure 3

Total	depth	(ft)
1. Humble Oil Company #1 Pickell	Sec. 21-13S-2W Union County, IL	8,492
2. Texas Pacific Oil Company #1 Farley	Sec. 34-13S-3E Johnson County, IL	14,284
3. Exxon #1 Duncan	Sec. 5-M-22 Webster County, KY	15,200
4. Texas Gas Trans. #1 Shain	Sec. 10-L-36 Grayson County, KY	13,551
5. Benz Oil #1 Nunnally	Sec. 16-F-46 Metcalfe County, KY	6,114

Figure 4

1. Texas #2614 Brown (Indiana Farm Bureau)	Sec. 20-5N-2E Lawrence County, IN	6,806
2. E. I. DuPont #1 WAD FEE	Sec. 10-U-44 Jefferson County, KY	5,954
3. Langford Oil and Gas #1 Knight Bros.	Sec. 6-P-35 Breckinridge County, KY	6,065
4. Texas Gas Exploration #1 H. Shain	Sec. 10-L-36 Grayson County, KY	13,551
5. Benz Oil Co. #1 Nunnally	Sec. 16-F-46 Metcalfe County, KY	6,114
6. Houghland & Hardy #2 S. Goad	Sec. 12-A-43 Macon County, TN	5,048
7. E. I. DuPont #1 FEE	Sec. 16-3S-35E Davidson County, TN	5,574
8. Texaco #1 B. Haynes	Sec. 10-7S-39E Wilson County, TN	5,756
9. Gordon Street #1 R. Holden	Sec. 13-10S-37E Rutherford County, TN	5,631
10. Staufer Chemical Co. #1 FEE	Sec. 16-12S-28E Maury County, TN	6,473
11. California Co. #1 E. W. Beeler	Sec. 4-15S-29E Giles County, TN	5,750
12. Shenandoah Oil Corp. #1 F. W. Smith & Occidental Pet.	Sec. 26-9S-2W Cullman County, AL	8,270

LIST OF WELLS

(continued)

Figure 5

1. Union Oil Company #1 Cisne Comm.	Sec. 3-1S-7E Wayne County, IL	11,614
2. Texaco Oil Company #1 Cuppy	Sec. 6-6S-7E Hamilton County, IL	13,051
3. Texas Pacific Oil Company #1 Streich	Sec. 2-11S-6E Pope County, IL	14,942
4. Texas Pacific Oil Company #1 Farley	Sec. 34-13S-3E Johnson County, IL	14,284